Semiconductor Technology: The Infrastructure That Lies Beneath

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Electronics and semiconductors

Last year the global electronics industry produced over $1.1 trillion ($1.1 million million) worth of products, three percent of the gross world product. Electronics was two percent of the world product 12 years ago, and is forecast to reach four percent in only four more years. This accelerating growth reflects the widespread belief that electronics brings value to productivity, communication, health care, and many other positive aspects of life.

Almost without exception, electronic products require semiconductor devices to provide their brains and muscle. Fifty years ago, in 1952, only $19 million worth of semiconductor devices were sold. These went mostly to development programs that could pay their necessarily high prices. Few appeared in consumer products. Last year, $200 billion worth of semiconductors were used to build the world's electronics, ten thousand times the market value in 1952. Furthermore, today's microcircuits each have about 100 million times the functional performance of the first micro-devices in the mid-1960's. Each transistor in the first microcircuits cost well over $1. A dollar today buys a million transistors.

The transistor has wrought more change in 50 years than any other innovation in history. The rapid development of semiconductor technology and the remarkable reductions in cost per function of complex microcircuits worked quickly to replace vacuum-tube technology. These made possible the creation of many uses for electronics that could not be foreseen in 1952.

Standards for completed semiconductor devices

Standard specifications for physical configurations of semiconductor devices such as individual transistors and higher-power devices originally were developed by the EIA.[1] Internationally, IEC[2] Committee TC-47 on Semiconductor Devices developed standards, principally for finished products but also for tests on finished but unpackaged chips. Present-day microelectronic devices are so often designed for specific and rapidly changing applications that standards for physical configurations now have limited value.

[1] (U.S.) Electronic Industries Association, now the Electronic Industries Alliance.

[2] International Electrotechnical Commission.

Standards for the manufacture of semiconductor devices

However, standards are essential for the materials, processes, and equipment used to make integrated circuits and other semiconductors. These items comprise the manufacturing infrastructure for semiconductor devices of all types, regardless of their application. Manufacturing equipment and consumable materials are made in most industrialized nations and sold throughout the world. Global sales were valued at $63 billion in 2000, a third of that of the semiconductor device industry. The significance of this sector is greater than one would suppose, because the process technology for device manufacturing is integral to the tools and the materials provided by this infrastructure, and thus is provided by the supplier, not the user.

Historical background

Test method standards for materials required in transistor manufacturing, developed by ASTM[3] Committee F-1 on Electronics, first appeared in 1958, the same year as the initial standards for external dimensions and electrical connections of transistors were published by JEDEC.[4] NBS was actively involved in both organizations. NBS development programs had existed for many years in vacuum-tube metrology. New work was started in metrology for semiconductor materials and devices to support the work of both JEDEC and ASTM. As vacuum tubes were supplanted by transistors, the content of the NBS programs changed as well. NBS and NIST staff members have been continuously active in ASTM and JEDEC in both technical and leadership roles. At the invitation of the DIN,[5] a NIST staff member provides liaison between the relevant ASTM and DIN committees. NIST staff also have contributed significantly to the SEMI[6] standards program described below.

[3] American Society for Testing and Materials.

[4] Initially the Joint Electron Device Engineering Council of the EIA and the (U.S.) National Electrical Manufacturers Association. Now the JEDEC Solid State Technology Association, a member of the EIA.

[5] Deutsches Institut fNr Normung (German Standards Institute).

[6] Semiconductor Equipment and Materials International. Prior to 1988, Semiconductor Equipment and Materials Institute. Founded 1970 as a U.S. industry association. Began its standards development program in 1973. Standards work was extended to both Europe and Japan in 1986.

By these means, the standards produced by these organizations benefit by incorporating NIST's metrological developments. In return, NIST gains a better understanding of the industry's needs from long-term contact with the industry experts on these committees. NIST's cooperative involvement in transnational standards activities also helps to avoid differences in standards that might become non-tariff barriers to trade.

By the late 1980s, the technology used by the semiconductor industries included many topics outside the expertise existing in NIST's semiconductor metrology program. An Office of Microelectronics Programs was established to plan and support new metrology development projects wherever in NIST the necessary skills existed. The National Semiconductor Metrology Program that evolved serves not only as a funding and project oversight activity, but as an entry point for use by the industry in contacting NIST experts, as a resource for NIST staff in locating industry peers, and as the focus for NIST's participation in SIA Roadmap development and in the standards activities mentioned earlier.

Global operations require global standards

As the semiconductor device, manufacturing equipment, and materials industries grew, they established manufacturing operations outside their home countries. This development was principally driven by the need to manufacture in locations near foreign customers, to allow more timely response to their needs.

This move to global operation resulted in the major (and many smaller) suppliers of devices, materials, and equipment having manufacturing operations in every significant customer area: Europe, North America, Japan, and Southeast Asia. Supplier firms prefer to make the identical products for all their customers. Customers, which are also global, prefer to have their suppliers provide identical products to all of their locations. These mutually reinforcing preferences lead naturally to a need for standards that are equally global.

Such standards must be created by global consensus to be acceptable for global use. In general, nationally-based standards have failed to be widely accepted, in part because potential users of the standards in other countries perceive them as serving national purposes inconsistent with the interests of a global industry.

The principal exceptions have been standard test methods. These are usually developed by small regional groups of experts. Direct global participation is difficult to establish and maintain. The most successful producers of test methods for semiconductor manufacturing have been ASTM, DIN, and JEITA.[7] These groups maintain close coordination in the semiconductor field, which mitigates to some extent their national nature. Until recently, most of the standards from DIN and JEITA were published only in German or Japanese. Nearly all DIN semiconductor test methods are now published in English as well as in German, and JEITA produces English versions of their test methods whenever they are revised. The technical excellence of these standards has given them global acceptance, in spite of the lack of significant global participation in their development.

Timing requirements for microelectronics

Since 1991, the SIA[8] has developed and published a series of consensus-based, long-range, technological forecasts that reflect historical trends in the microelectronics industry and project anticipated needs for manufacturing technology 15 years into the future. In 1997, participation in this process was extended to European, Japanese, Korean, and Taiwanese industry associations as well. This collaboration produced the 1999 International Technology Roadmap for Semiconductors, a global technological consensus. A new edition will appear late this year. The 2001 edition will define the technology expected to be required for new microelectronics generations, each providing a four-fold increase in performance, foreseen to appear every three years until 2014.

Consequences for standards development

This rapid evolution of microelectronic devices places severe demands on both manufacturing equipment and materials, which must be modified, improved, or re-developed in advance of this time scale to meet requirements for making more advanced devices. Early models of new tools and initial quantities of improved or new materials are required to permit development and pilot production of each succeeding generation of microcircuits.

This means standards must be developed or updated on the same time schedule, in a global process, with expert technical participation from every part of the world where semiconductor devices, manufacturing tools, or materials are made. No conventional international standards process is capable of meeting these requirements.

[7] Formerly Japan Electronics Industry Development Association, now Japan Electronics and Information Technology Industries Association.
[8] (U.S.) Semiconductor Industry Association.

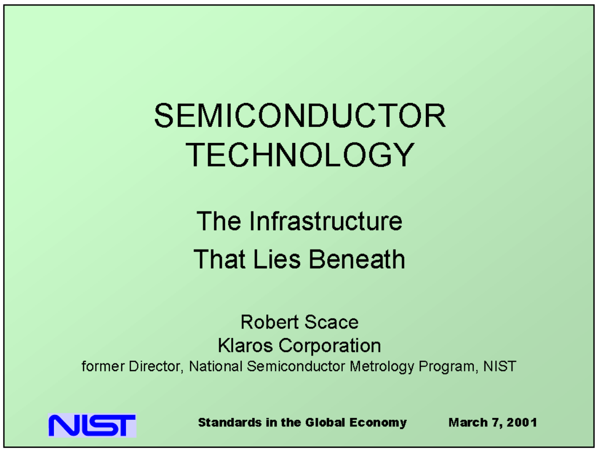
The industry's solution

Most standards for semiconductor manufacturing, by a large margin, are produced by SEMI, a global semiconductor industry association of nearly 2,500 member companies. SEMI has produced about 450 manufacturing standards for the semiconductor and flat panel display industries. Nearly 2,500 individual technical committee members in Asia, Europe, and North America participate in this work. These are voluntary standards, in the sense that their use is not mandated by government authorities, but driven by business needs. SEMI's program is an open, voluntary, full-consensus method of standards development. Being an international industry organization, SEMI does not submit its standards to any national standards organization.

When necessary, SEMI can develop and publish a new full-consensus standard in one year. Revisions can be quicker. Technical committee meeting reports are published on the SEMI Web pages within three weeks after a meeting. Standards whose letter ballots are accepted at a technical committee meeting and also pass procedural review (which can occur during the same week) are published on the Web within two months and in CD form within at most four months. SEMI standards are also published in Japanese on CD and paper and in Chinese on paper.

This creative use of modern communication tools in standards development and in procedural review provides impressive speed of development and publication. The high quality of the standards is indicative of the technical competence of the volunteer members of the program. SEMI, in common with most standards developing organizations, provides quality control of the process but not technical review of the content of a standard.

The SEMI process is not international as defined by ISO and IEC, but it is international from nearly any other point of view. The process focuses on the specific needs of a global high-technology industry and serves those needs well. These are business needs, not national or international political needs. The process is global in its use of large international groups of experts to develop standards, in its support from a substantial international consensus for accepting the product, and in its service to an essential international business community. It may serve other fast-moving global industries equally well.



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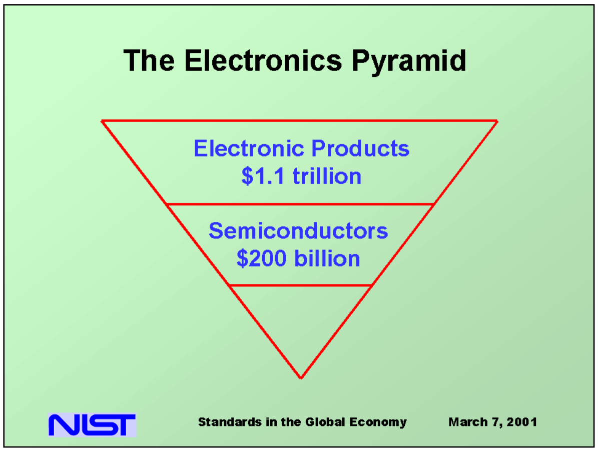

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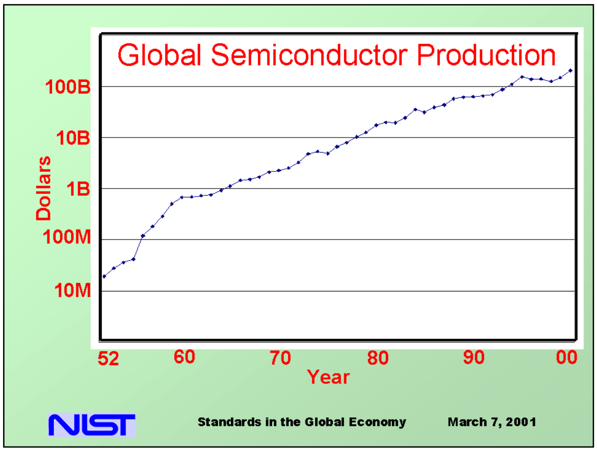

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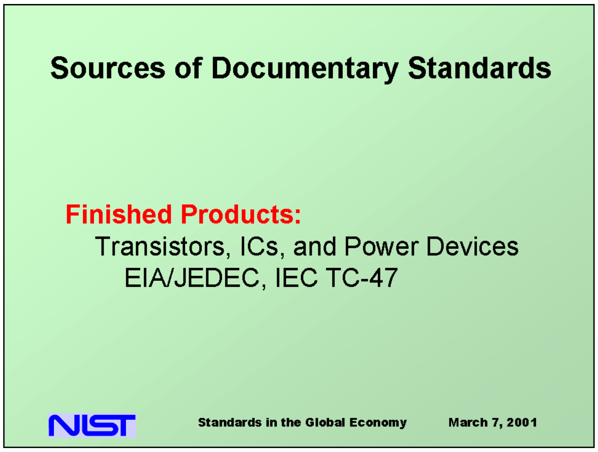

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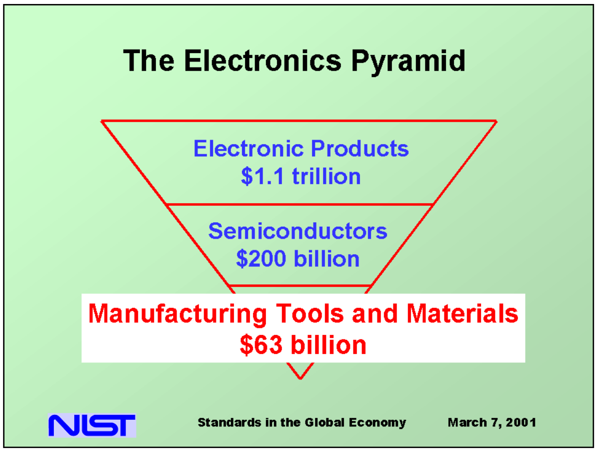

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NIST Standards Involvement

1989 Industry needs broader technical range of NIST metrology development
1991 New NIST-wide program begins
1993 National Semiconductor Metrology Program formalized

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Semiconductor Industry's Needs

Standards that are
- industry based, not politically based
- globally developed
  - broad base of participation
- globally accepted

TIMELY

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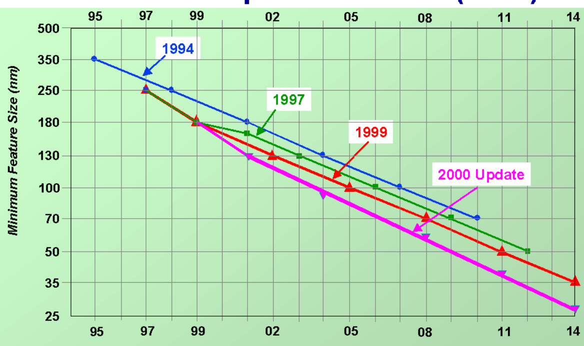
ITRS Roadmap Acceleration (2000)



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The Industry's Solution

SEMI International standards program

Started in 1973; international since 1988
450 manufacturing standards to date

Open, voluntary, full-consensus method

Standards not submitted to national bodies

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The Industry's Solution

New standard possible in one year
Committee reports on Web in 3 weeks
New or revised standards on Web in two months
Publication three times annually
- English and Japanese on CD
- Japanese and Chinese on paper

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The Industry's Solution

Delivers on time
- Global business needs met
- Global consensus support
- Global acceptance
- International in fact

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